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Haptic contact in immersive 360° cinematic environment

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Abstract

We perceive the environment around us using the five senses that are categorized as visual, auditory, haptic, olfactory and gustatory. A considerable amount of work has been done in the audio-visual domain compared to the rest. With new head-mounted displays in the consumer market, immersive VR is becoming ubiquitous and by adding additional sensory feedback, we aim to enhance the user experience and increase presence in Virtual Environments. There has been previous research on haptic interfaces. This thesis explored how haptic feedback in the form of wearable feedback (vest based) and non-wearable (ground vibrations and wind simulations) interfaces influences the feeling of presence in 360° cinematic environments. Prototypes of wearable and non-wearable interfaces were designed as part of a simulation system to experience a 360° cinematic experience with feedback. A user study was carried out to investigate how the sense of presence varies due to the inclusion of haptic feedback. The study also compared wearable and non-wearable interfaces in terms of sense of presence. From the analysis of the results, though we were not able to find any significant difference in the sense of presence between wearable and non-wearable feedback, a significant improvement in sense of presence, realism, involvement and overall immersion was observed with the inclusion of haptic feedback to the 360° cinematic environment.

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Abbreviations

VR	V irtual R eality
MR	M ixed R eality
AV	A ugmented V irtuality
AR	A ugmented R eality
HMD	H ead- M ounted D isplay
CG	C omputer G raphics
GE	G ame E ngine
CD	C ontrol D river
HI	H aptic I nterfaces
PWM	P ulse W idth M odulation
SDK	S oftware D evelopment K it
HAVE	H aptic A udio V isual E nvironments

Chapter 1

Introduction

1.1 Motivation

Anthropologists tell us that storytelling is central to human existence and that it is common to every known culture. In modern days, movies are considered the most popular medium for the same. Since the inception of the first motion picture more than a century ago, film and television have been at the cutting-edge of entertainment and technology. Innovations in film making have been transporting audiences to new worlds through 4D theaters and immersive movie-going experiences, recording 48 frames-per-second at 4K resolutions. With the digital age, the movie industry has grown with the advancement in technologies such as computer graphics (CG), spatial high definition audio and advanced computational processing. With the advancement in VR technology, filmmakers are looking at another potential medium for immersive storytelling.

The fact that in virtual reality (VR), the digital environment completely surrounds the user's field of view and offers a new way to connect with the digital content provides a new medium for cinematic storytelling that sets it apart from the conventional cinematic media such as TVs. In VR, the viewer is the master of his/her own perspective; s/he can look in any direction, and perhaps even interact with the scene. With this freedom introduced by the technology, there are many questions arising on how the movie content has to be produced. What should the viewers be allowed to do to prevent them from missing any part of the story? Should the story be linearly structured, or should it change with the viewer's actions? If a group of friends wants to watch it together, how

would the experience be? How do animated movies compare with traditional movies in VR? Some of these questions will take years to solve, and more will arise along the way. The arrival of affordable high-quality head-mounted displays (HMDs) has accelerated the process of answering these research questions. Among various different VR techniques applicable, 360° panorama video is one of the most actively adopted methods of movie production. In 360° movies, the viewer is completely surrounded by a spherical video background, and s/he has control over their perspective.

With the emerging popularity of consumer VR headsets, it is becoming easy for people to experience VR. Most of the research studies that are being conducted in this domain require expensive equipment and laborious installations which are not always very practical. When it comes to immersive experience, the essence of “being there” is of great importance. With the advancement of technologies like 3D CG, VR, Augmented Reality (AR), Augmented Virtuality (AV), the possibilities for the future of immersive entertainment experiences show substantial potential. Most of the current technologies cater to audio-visual senses but not to haptic/olfactory/gustatory senses. Even when the audio-visual senses perceive a realistic world filled with atmospheric sounds, it is hard to make the user feel present since humans have more than audio and visual senses [4].

The introduction of haptics in VR has been of research interest for more than two decades. Previous studies have tried to recreate experiences and intuitive interfaces using different haptic devices. One of the main objectives of these studies has been to find innovative ways to feel and interact with the virtual objects as easily as they do with the real-world objects.

According to Burdea, haptic feedback groups the modalities of force feedback, tactile feedback, and the proprioceptive feedback [5]. Virtual object hardness, weight, and inertia can be integrated into a VR simulation via Force feedback where as a feel of the virtual object surface contact geometry, smoothness, slippage, and temperature can be represented using tactile feedback.

With the huge importance of visuals in providing an immersive watching experience, 360° panoramic images/video content is becoming increasingly available for HMDs. For example, YouTube has a plethora of 360° videos and Google has photosphere¹ for Street View. 3D experiences with live film content are challenging and involve addressing

¹<https://www.androidcentral.com/photo-sphere>

complex problems in CG, such as being able to estimate 3D geometry, materials, lighting, and other extensive 3D scene information [4].

There have been extensive research in the direction of enhancing the 360° movie experience in VR. For example, prior work [4, 6] has investigated interaction and inclusion of the viewer's body inside the 360° movie. Taking this to the next step, this thesis explores how the sense of touch (haptics) influences the user's sense of presence and embodiment in VR 360° movie experience. It encompasses the development and implementation of wearable and non-wearable haptic devices to enhance the immersive environment for future home entertainment. In the experiment setup, users viewed the virtual content on an Oculus Rift² with synchronized haptic feedback incorporated with the digital content to enhance immersion.

1.2 Research Questions

The research questions we are aiming to answer with the designed system are:

- Does haptic feedback in a cinematic virtual environment improve a user's sense of presence?
- How do haptic feedback through wearable and non-wearable interfaces compare against each other in terms of sense of presence?

1.3 Contribution

The main contributions of this thesis are:

- A novel method to provide feedback in 360° cinematic environments using wearable and non-wearable haptic interfaces.
- A user study to investigate the influence of haptic feedback on the sense of presence.

²<https://www.oculus.com/rift/>

1.4 Thesis structure

The structure of the thesis is as follows.

Chapter 2: Discusses the related work done on presence and multi-sensory-immersion based cinematic environment, human haptic system, related studies in wearable and non-wearable feedback.

Chapter 3: Explains the design process of the prototype.

Chapter 4: Presents the implementation of the prototype.

Chapter 5: Describes the user experiment in detail and discusses each step of the evaluation process.

Chapter 6: Describes the results obtained from the user study.

Chapter 7: Discusses the results found and describes the limitations of the study.

Chapter 8: Concludes the thesis and identifies possible future areas of research.

Chapter 2

Background

VR can be described as a computer-generated three-dimensional environment. According to Burdea and Coiffet [5], VR has been defined as I^3 (Immersion-Interaction-Imagination). Even though immersion in VR includes multiple sensory inputs, most of the VR applications concentrate on enhancing the quality of audio-visual cues. Haptic feedback is an important sensory modality to provide immersion as humans use their “sense of touch” while interacting with the real world objects. The inclusion of haptics is a step-up to provide a realistic immersive user experience in VR.

2.1 Immersion and presence

Immersion is the ability of the VR system to trick the user into feeling that they are somewhere else. Factors that affect immersion, include isolation from the physical environment, the perception of self-inclusion in the virtual environment, natural modes of interaction, and perception of self-movement [6].

Presence is how they are really engaged and feel themselves inside the virtual world. Presence can be defined as a state of consciousness or the psychological state of being there [7]. The degree of involvement people experience depends on their focus and attention on a set of stimuli or events, depending on the extent to which they perceive them to be meaningful or significant. As users focus more on the VR stimuli, they become more involved in the VR experience, which leads to an increased sense of presence. In

our study, we tried to improve the sense of presence in 360° cinematic environment with the inclusion of haptic feedback.

2.2 Human Haptic system

Our senses are physiological tools for perceiving environmental information [8]. Aristotle classified human senses into five categories: sight or vision, hearing or audition, smell or olfaction, touch or tactition, and taste or gustation. Each of the sense modalities are characterized by many factors, such as the types of received and accepted data, the sensitivity to the data in terms of temporal and spatial resolutions, the information processing rate or bandwidth, and the capability of the receptors to adapt to the received data [8].

Unlike the other four senses, the sense of touch is distributed through the body and different parts of the body have different sensitivities. These sensitivities vary because the skin is an interface that centrally discriminates four modalities of sensation, namely touch (including both light touch and pressure), cold, heat, and pain [8]. Furthermore, a combination of two or more modalities can be used to characterize sensations such as roughness, wetness, and vibration. To appreciate the sense of touch more fully, consider the following facts: according to Heller and Schiff [9], touch is twenty times faster than vision, so humans are able to differentiate between two stimuli just 5 ms apart; Bolanowskiet al. found that touch is highly sensitive to vibration up to 1 KHz, with the peak sensitivity around 250 Hz; and skin receptors

For instance, in the case of holding a cup, we first run our fingers around the cup to form a mental image of the cup which in turn helps us to hold the cup properly by applying the right pressure. This bidirectional flow of information is often referred to as active touch. This distinguishes the sense of touch from other senses.

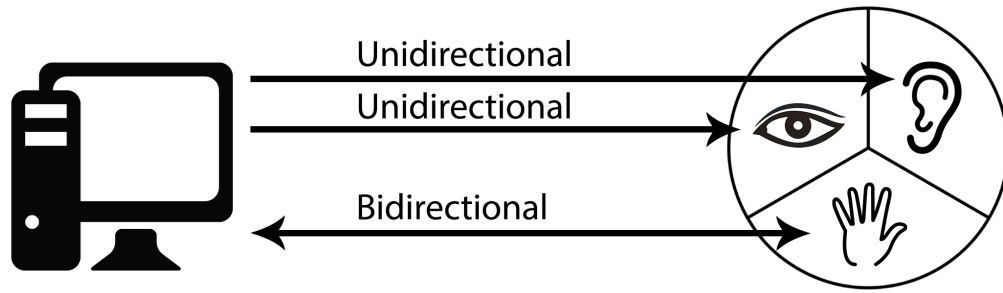


FIGURE 2.1: Haptics bidirectional feedback

Based on these studies, while designing the haptic interface system, we need to understand the way the human haptic system works, create mechanical devices that replace/augment the sense of touch, and create computer logic to facilitate interaction. We followed this approach in developing the haptic interfaces for this study.

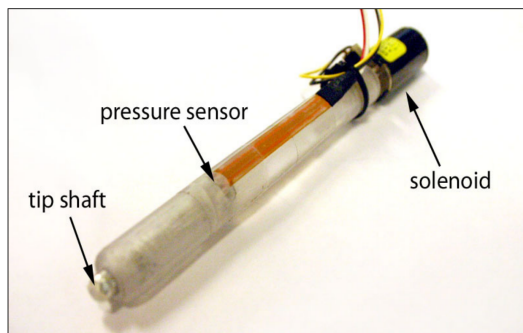
2.3 Technologies for feedback

2.3.1 Vibrotactile Feedback

Our work is guided by a large body of work in psychophysics [10]. Cutaneous(skin) sensitivity is generally accepted to be logarithmic in nature, both for the detection of pressure as well as the resolution of frequency [11]. Some of the most prominent technologies that drive haptic interfaces are described here.

The most widespread technology used to generate vibrotactile is the offset DC motor. Despite the limitations of the technology, researchers have been able to generate a wide variety of uses for vibrotactile feedback. Li et al. [12] developed a technique similar to pulse width modulation that generates output in the order of 10 different amplitudes of vibration. The C2 Tactor [13] uses an alternative approach, generating vibration by moving a small contactor via a voice coil actuator. Brown and Brewster have done a significant amount of work with the C2 Tactor showing how a variety of haptic icons can be generated by modulating waveform and location [14–16]. Chang et al. [17] use a similar approach with Multifunction Transducers that allows a single actuator to be used for vibration and audio.

The sense of touch has also been proposed as a way of information display. HandJive [18] explored how users would communicate with a haptic input/output device using force-feedback while Chang’s ComTouch [19] explored how users would communicate with one-another using vibration. Luk et al. [20] implemented an array of piezoelectric tabs to generate lateral skin stretch, allowing different waveforms to be felt under the thumb. Lee et al. [21] developed a Haptic Pen (figure 2.3) which used a solenoid to mimic the feeling of pressing down with a stylus. Rubbing and tapping (figure 2.3) have been proposed as input mechanisms for interacting with touchscreens and with synthesized surfaces [10], but not as forms of feedback.



(a) Lee’s Haptic Pen



(b) Li’s Rubbing and Tapping - sound touch prototype.

FIGURE 2.2: Vibrotactile interfaces

Generally speaking, the choice of actuators to be used is mainly determined by the role of vibrotactile feedback in the interface design, and by other factors such as size, power consumption or the information to be conveyed.

2.3.2 Wind Feedback

Various studies have been conducted in the past in the direction of using wind display. Sensorama [22] was one of the earliest examples. Sensorama was a motorcycle simulator that used wind cues to enhance immersion. To provide ambient wind cues, Windcube placed 20 fans close to the user inside a frame [11]. VR Scooter [1] provided wind and

vibrational feedback to simulate collision in locomotion. Virtual Sailing [23] showed that movement wind cues enhance the sense of presence. WindWalker [24] implemented head mounted wind feedback for orientation. Wind and Warmth [25] provided wind and heat feedback inside a cage structure. They used fans to provide wind and color foils mounted on top of infrared lamps to generate heat.



FIGURE 2.3: Vibrotactile interfaces

These studies explore movement, object, ambient and informational cues. Though there are multiple ways to implement wind feedback, most studies prefer fans as the source. In our study, we implemented wind feedback using fans due to simplicity.

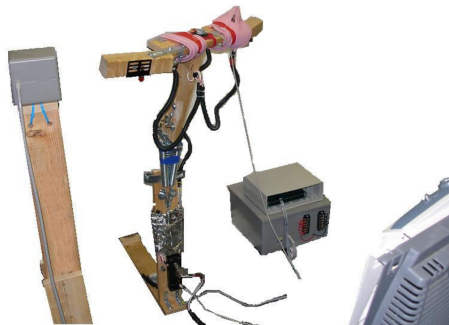


FIGURE 2.4: VR Scooter [1].

Cues	Ambient	Movement	Object	Informational
Wind	WindCube [11] Wind- Warmth	Sensorama [22] VRScooter [1] Virtu- alSailing [23]	WindWarmth [25]	WindWalker [24]
Vibration		KKE [30] Planter [31] Sensorama [22]	VRScooter [1]	WYSIWYF [32]

TABLE 2.1: Related Wind Vibration Studies

2.4 Wearable Haptic Interface

The way humans perceive stimuli plays an important role in the approach towards wearable haptics. Various strategies have been used to deliver stimuli - vibrations, applying force, pin-arrays to simulate skin, electrocutaneous feedback etc [26]. To discriminate the location where a vibrotactile stimulus was presented, Cholewiak and colleagues [27, 28] carried out a series of experiments. The possibilities consisted of seven points of the forearm, three points on the upper arm, two points on the shoulder and seven points around the lower torso. Results showed poor performance for what concerns the forearm, with results superior to 70% only in two points, the elbow and the wrist. Better results were achieved for the torso, for which all the points were identified more than 70% of the time, with peaks up to almost 100%. Van Erp et al. [29] showed that the torso has a spatial acuity of about 3cm, remarking however that the discrimination is highly dependent on two temporal factors as well: the duration of the stimuli and the temporal offset between two consecutive stimuli. Most HMDs have handheld controllers and hence it would be tricky to accommodate haptic devices in the hand/wrist. In which case, wearable feedback directed at torso made sense.

2.5 Non-Wearable Haptic Interface

There have been many studies related to non-wearable feedback interfaces. Some of the studies we referred are mentioned in table 2.1.

Sensorama [22] and VRScooter [1] used vibrational feedback among other cues to provide an immersive environment. KKE [30] used Vibro tactile tiles located under feet for tactile rendering to enhance sensation of walking in virtual environments. Planter [31] showed enhanced realism in walking with the inclusion of haptic feedback. WYSIWYF Display [32] is a vision-based, object-tracking technique that registers the image displayed on a visual interface to a haptic interface. These studies were influential in the selection of non-wearable haptic interfaces for the prototype.

2.6 Design of Multi-Sensory Cues

Feng’s [2] multi-sensory design space explored the multi-sensory cues in a virtual environment. We updated her table that mapped sensory cues against category with wearable haptic feedback as shown in 2.5. The multi-sensory cues are grouped on sensory channels as well as based on their use.

Senses	Cues	Ambient	Object	Movement	Informational
Visual	General	Ambient Light	Visual Landmarks	Visual Flow	Information Panel
Auditory	General	City-street Noise	AC Hum	Footstep Sounds	Audio Instructions
Haptic	Wind	Atmospheric Wind	AC Airflow	Movement Wind	Directional Wind
	Floor Vibration	Factory floor vibration	Floor-type AC	Footstep Vibration	Proximity Alert
	Vest Feedback	Rain	Bullets Hitting	N/A	Directional Information
Olfactory	General	Smell of the sea	Fruit Smell	N/A	Rosemary Indicating CO
Gustatory	General	N/A			

FIGURE 2.5: Sensory cues mapped against categories.

Ambient cues are hard to identify and provide a natural atmosphere to the user like experiencing wind. **Object Cues** refer to the sensation of interaction with objects

like being hit by a ball and **Informational Cues** provide information like the sense of direction.



FIGURE 2.6: Feng's Multi-Sensory feedback system [2]

2.7 Our Work

As described in this chapter, previous studies have explored in immersion and sense of presence with various haptic interfaces in a virtual environment. However, 360° cinematic environment is a relatively unexplored area in this domain. The novelty of our study is that we are investigating the influence haptic feedback in the sense of presence in a 360° cinematic environment. Additionally, we are also interested in the comparison of wearable and non-wearable haptic interfaces in terms of sense of presence. The studies referred to in this chapter had been influential in designing the prototype which is described in the next chapter.

Chapter 3

Design Process

We started with the objective of developing a system that introduces wearable and non-wearable haptic feedback to the user while the user is watching a 360° movie. We explored the previous studies that were conducted in the domain of wearable and non-wearable haptic feedback. This helped us in determining the suitable interfaces. The design process that was undertaken to devise the prototype is outlined in this chapter. The design process started at gathering requirements, which was followed up by a rigorous thought process that led to the drafting of a design plan for the prototype.

3.1 Requirements Gathering

Initial requirements for the system can be classified as:

- **Simulator** to facilitate 360° video playback and to control haptic interfaces.
- **Wearable and non-wearable interfaces** to provide the feedback.
- **Control Software** to simplify communication between the simulator and the interfaces.

The components listed above were classified into modules so as to focus on building one thing at a time. We looked at possible ways to bring all the modules together and drafted an architecture of how the interfaces would interact with the simulator to provide

an immersive experience. A user experiment was planned to assess the effectiveness of the system.

3.2 Design Considerations and Thought Process

One of the main aspects of our study deals with the way feedback is delivered to the user. For this, we classified feedback into two categories: wearable VS non-wearable feedback and Vibro-tactile vs Wind feedback. The initial plan was to evaluate both the categories, but the latter was dropped from the scope of our study but is included in the future discussion section.

Hardware considerations for the system included HMD, wearable vibrotactile feedback interface in the form of a vest and non-wearable feedback interfaces using wind and floor vibration. In terms of software considerations, we required a simulator system for 360° video playback along with synchronized triggering of the feedback interfaces. We envisioned the process of synchronization to be similar to a timeline track of digital content editing software. This would simplify synchronization of the feedback. We also needed a platform that could communicate with the HMD and interfaces with ease. Moreover, the platform should be able to seamlessly incorporate all modules into a single system.

Based on these considerations, we were able to narrow down the requirements into Game Engine(GE), Wearable Feedback interface, Non-Wearable feedback interface and Control Driver(CD). Each of these modules is described in detail below.

3.2.1 Game Engine

Some of the studies [1, 2, 22, 24, 25] we referred used programming languages to create the virtual environment. This approach is rather time consuming. We found that modern day game engines are very powerful in the sense that implementing game logic is much faster than starting off with a programming language and setting up the environment. Considering all these requirements, we decided to use game engines as they have native HMD support and can communicate with interfaces. Hence to set up the logic framework of our prototype we narrowed our options to two platforms - Unreal and Unity. Both the

game engines had their own advantages and disadvantages. Though the prototype could be made in either of the platforms without any significant difference, we opted Unreal Engine due to personal preference.

3.2.2 Wearable Feedback

As part of our study, we wanted to compare wearable and non-wearable feedback. Wearable feedback is the feedback that is given through an interface that the user wears. A number of research groups have investigated the development of wearable feedback interfaces. For our wearable haptic prototype, we investigated three different vest based feedback devices based on their availability and accessibility (at HIT Lab NZ). They are:

- “KOR-FX”¹ - uses proprietary acousto-haptic technology. The advantage was that it was wireless and relatively simple. It provided feedback based on audio input and had a very low resolution. Figure 3.1a shows the vest design.
- “3D Space”² - uses 8 air-powered “active zones” to generate impact force when the data is fed from the game. It was suitable for our purpose, but making the vest wireless was a challenge. Compatibility issues also raised concerns. Figure 3.1b shows the vest design.
- Our third option was to try out vest based on the study “Beyond Visuals” [3]. This was relatively easy and cheap to replicate based on popular micro controllers. The simple operational logic and higher resolution made it an ideal choice.

¹<http://korfx.com/>

²<http://tngames.com/products>



FIGURE 3.1: Commercial Haptic Vests

One of the crucial parts of designing the vest is the evaluation of spatial resolution of the tactile senses. In our design, we borrow the garment design, tactor placement and wiring from the TactaVest [3] as this addresses some of the major issues like the variation in the size of potential wearers. The TactaVest is designed to hug the wearer through a large range of motion, while still granting adequate freedom of movement [27, 28]. Our approach to wearable haptics is influenced by this work. We planned to incorporate this concept with popular micro-controllers and to implement wireless technology for communication.

3.2.3 Non-Wearable Feedback

Non-wearable feedback is the feedback that the user experiences from the surroundings while watching the 360° movie. These interfaces may not necessarily be in contact with the user. In our study, the non-wearable feedback constitutes of two main components - Wind and Ground vibration. Wind module provides wind feedback to the user. For delivering wind feedback, we planned a cage structure that surrounds the user. This would facilitate the placement of fans so as to provide omnidirectional wind feedback to the user. The setup was influenced by Feng's experiment [2]. The intensity of the wind feedback is delivered in accordance with the actions in the scene.

Ground Vibrations were planned to be delivered through an elevated floorboard on which the user stands. The proposed implementation strategy was either to send vibration signals to the module from the game engine or to route the audio to the actuators via a low-pass amplifier. We finalized on the latter due to the simplicity it offers over the former.

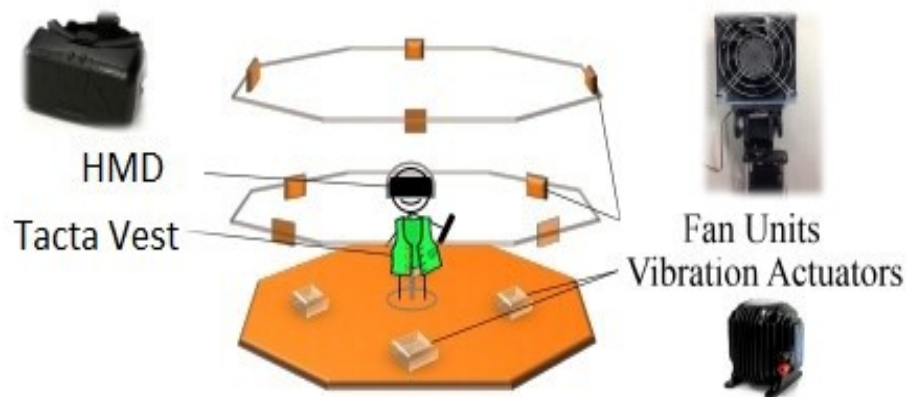


FIGURE 3.2: Proposed multi sensory feedback system [2]



FIGURE 3.3: Lindeman's TactaVest for information display [3]

3.2.4 Control Driver

We decided to construct a control driver for the purpose of testing and monitoring the haptic interfaces. The primary objective of the control driver is to facilitate the communication between the game engine and the connected peripheral devices. Another requirement of the control driver was to provide a graphical interface to test and debug the components. This is very helpful in the development phase as the Unreal engine is

heavy on resources and frequent restarting of simulations is a tedious task. The software also needs to be developed with the focus on accommodating other devices/future enhancements to the system with ease if need be.

3.3 System Design Overview

According to the design plan, the main components of the prototype are:

- Simulator - plays the 360° video and triggers the interfaces synchronously.
- Wearable and non-wearable interfaces - provide the feedback while the user is immersed in a 360° cinematic environment.
- Control Driver - facilitates the connection between the simulator and the interfaces.

Combining all the individual components stated above, we envisioned a working prototype that uses the unreal game engine to play the 360° video and trigger the feedback interfaces. The trigger signals would be transferred through the control driver to the peripheral interfaces(Wind, Ground and vest module).

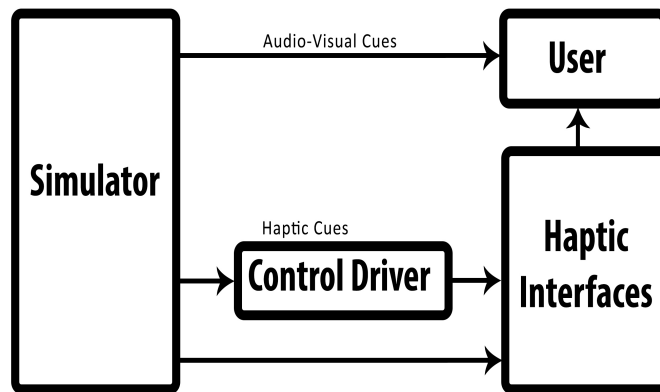


FIGURE 3.4: Preliminary System Design Overview

Chapter 4

Prototype Development

This chapter describes the implementation phase of the prototype. The prototype needed to be sturdy enough for experiencing an immersive 360° cinematic experience and to conduct the user study. This section discusses the prototype development. We created a system architecture to visualize the development.

4.1 System Architecture

As we can see from figure 4.1, the main components of system architecture are Game Engine, Control Driver, haptic interfaces and the user. They are broadly classified into two categories: Hardware (shaded blocks in figure 4.1 and Software. Game engine synchronously maps the feedback interfaces to the video playback. The control software assists in transmitting the trigger logic to the interfaces as well as in debugging them. We have classified the interfaces into modules which are discussed in detail below. All of these components work together to provide an immersive 360° cinematic experience.

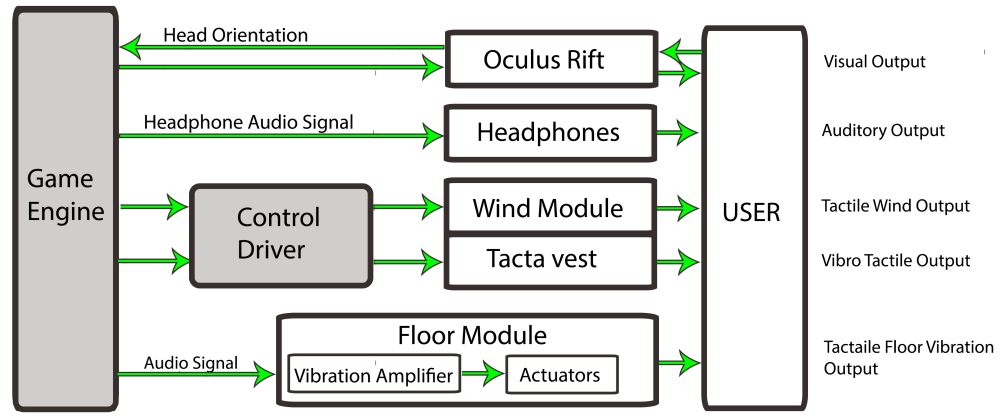


FIGURE 4.1: System Architecture

4.2 Hardware

4.2.1 TactaVest

The TactaVest is a wearable interface that provides vibrotactile feedback to the user. The vest is made of stretchable fabric to provide a snug fit. It is secured in place using Velcro strips. This design enables the vest to be used on a wide range of potential wearers. We 3D-printed a case to hide our electronics inside the vest.

The vibrotactile feedback is produced using small offset DC motors that are powered and controlled by an Arduino¹ mega with an expansion shield. Twelve of these units were used in the vest. Arduino mega has 14 PWM (Pulse Width Modulation) pins that cater to a voltage range of 0v to 5v which is mapped to a scale of 0-255 (in terms of intensity). The control driver will send the pin number and voltage (as intensity) to the Arduino board which will, in turn, activate the corresponding motor. A Bluetooth module was connected to the Arduino which facilitated the communication between the PC that runs the simulation and the vest.

¹<https://www.arduino.cc/>



FIGURE 4.2: Top view of the Vest

4.2.2 Wind Module

The wind module consists of a group of 16 fan units that are controlled by two Arduino boards. The boards are connected to the computer using USB connection. The fans are mounted on PVC pipes that form a cage-like structure around the user. The fans are also placed 20° apart from each other so that they effectively cover the area around the user (360°).

Fan unit hardware: Each unit (Figure 4.3b) has a 120x38mm DC fan (Delta AFB1212SHE-4F1C) that displaces over 151 cubic feet of air per minute mounted on a platform. Wind speed of each fan is controlled over a range from 0 to 255 which corresponds to 0 m/s to 4 m/s measured at a distance of 50 cm measured from the fan.

Fan layout: A top-down view of the fan-unit layout is shown in Figure 4.3a. The sixteen units are divided into two groups, eight are installed at a lower level (0.85m above the ground) while the others are mounted upside down at a higher level (1.9m).

Working: An Arduino is used to control the fans. Two of these were used with each of them controlling eight fans. Fans are driven through PWM pins of the Arduino. This enables us to regulate with a range of 255 steps. The Arduino communicates to the Control Driver through the serial port connection.

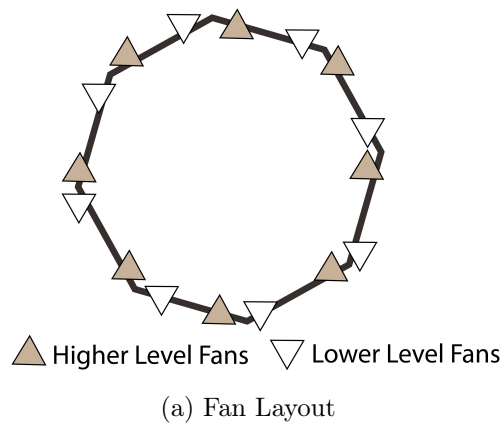


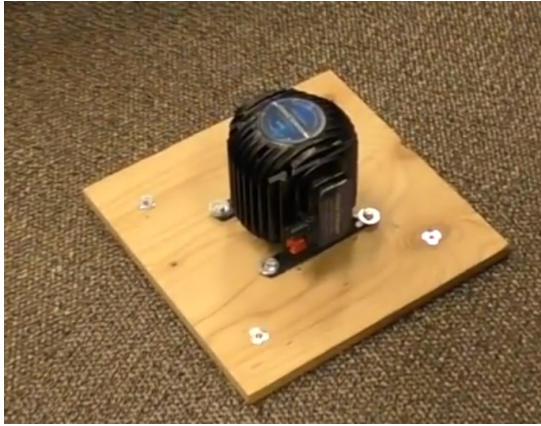
FIGURE 4.3: Wind Module

4.2.3 Floor Vibration Module

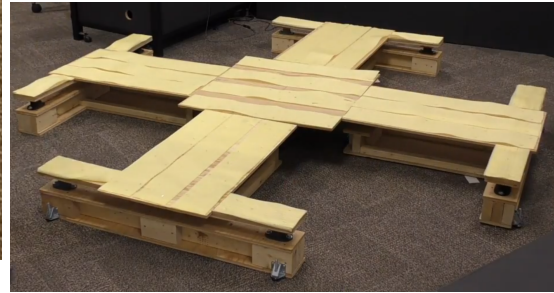
The floor module was made of a raised platform made of wood in the shape that accommodates itself inside the cage structure of the wind module. Four but-kickers² placed underneath the elevated platform provide the vibration feedback. The audio from the game engine was routed to a low pass amplifier and given to the buttkicker. An application called “Voice Meter”³ was used to split the sound stream from the game engine to the headset and the amplifier.

²<https://thebuttkicker.com/buttkicker-lfe/>

³<https://www.vb-audio.com/Voicemeeter/index.htm>



(a) Underside of the floor panel to which the buttkicker is bolted



(b) Skeletal frame of the floor.

FIGURE 4.4: Wind Module

4.2.4 Head Mounted Display

Top five HMDs in the market at the time of the study was considered for the prototype. They include Samsung Gear VR⁴, Sony Playstation VR⁵, “HTC Vive”⁶, Oculus Rift⁷, TCL Alcatel VR headset⁸.

Samsung Gear VR and Alcatel VR needed the simulation to be written in Android which was complex compared to game engines. Play station VR required a play station and HIT VIVE was comparatively expensive. Oculus is one of the oldest of the group, a lot of developers already use the platform to develop applications and try different hardware. The same applies to the newer consumer model Oculus Rift CV as it had good software and hardware platform compatibility. Moreover, Unreal Engine has built-in support for Oculus Rift. Hence Oculus Rift CV was used for our prototype.

4.2.5 Desktop PC

The recommended computer hardware for Oculus Rift is Intel i3-6100 / AMD FX4350 or greater processor, 8GB RAM or more, a Nvidia 960 or greater graphics card. The system

⁴<http://www.samsung.com/global/galaxy/gear-vr/>

⁵<https://www.playstation.com/en-nz/explore/playstation-vr/>

⁶<https://www.vive.com/eu/>

⁷<https://www.oculus.com/rift/>

⁸<https://us.alcatelmobile.com/virtual-reality-goggles/>

we used to develop the prototype was equipped with Intel i7-6700, 3.4GHz processor, 32GB RAM, NVIDIA GTX1080 graphics card and ran on Windows 10 operating system.

4.3 Software

4.3.1 Unreal Game Engine

Unreal Engine has tools that make it easy for developers to connect interfaces, control them and to create interactive 3D experiences. Unreal provides support for adding scripted behaviors to objects and the ease of interaction with a variety of input and interface devices. Another decisive factor for the selection of unreal engine was the inclusion of the tool - “level sequencer”⁹. This satisfied our requirement for a system that would enable synchronization of the feedback to the digital content and had minimum learning curve due to it’s resemblances to digital content editing software.

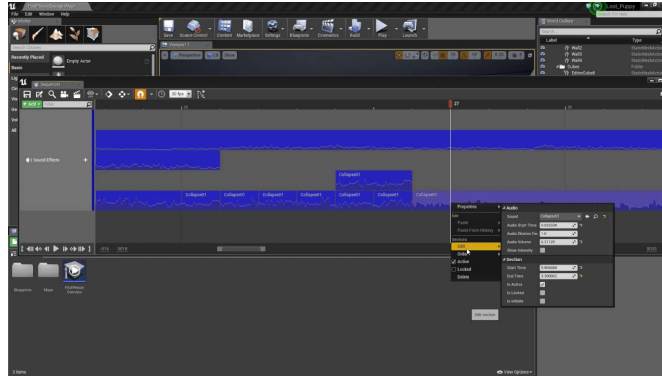


FIGURE 4.5: Unreal Engine level sequencer

Unreal engine communicates to the control software using socket connection. To implement socket connection, we used a plugin called “socket.io”¹⁰ for unreal engine. The vibration information(unit-number, intensity, and duration) would be sent to the control driver through a socket connection. Thereafter, Control Driver takes care of triggering the required interfaces.

⁹<https://docs.unrealengine.com/latest/INT/Engine/Sequencer/Overview/>

¹⁰<https://socket.io/>

4.3.2 Creating 360° Spherical Video Player.

Most of the 360° videos available online were equi-rectangular mapped videos which are spherical coordinate videos projected onto a planar coordinate. Unreal Engine supported the playback of these videos as they can be mapped into a sphere. Nonetheless, the game engine only supported playing the video, the spherical environment that needs to be mapped to the video needs to be created from some other source. Hence a spherical mesh from Unreal was exported into Blender to invert normals. Later this was imported into Unreal. Since the sphere already has the vertices and texture coordinates, it made the process of mapping the equirectangular videos easier. One downside is that the mapping will be done only on the outside of the sphere. In our case, the user is viewing from the center of the sphere and hence would not be able to view the mapped video that plays on the outside. The workaround for this was to make the media texture material of the sphere two-sided. This enables video playback on either side of the sphere as if the sphere was made of glass. Figure 4.6 shows the stages of mapping the 360° video to a sphere.



FIGURE 4.6: 360° VR player video mapping, a) Equirectangular mapped video b) Mapping Sphere c) Video player with inside mapping d) Viewer's perspective

4.3.3 Digital Content - 360° Video

As the 360° video contains the narrative of the immersive experience, it is one of the integral components of our project. In our study, the user can only view the environment, and there will be no interaction. While searching for the background video, realistic and animated videos were considered. Since we are interested in how haptics influences the immersion in VR, we looked out for video scenes that had the potential to implement haptics. That included environments like snowy, windy, explosive, earthquakes, harsh weather etc. With these guidelines in mind, we shortlisted potential videos for our prototype. Some of them are “Skiing”¹¹, “Great White Sharks”¹², “Roller Coaster 360”¹³, “1941 Battle: 360° Reenactment”¹⁴, “Invasion! 360 VR”¹⁵.



FIGURE 4.7: '1941 Battle 360°' screenshot

Creating an immersive experience seemed more plausible with these videos, as they provide the potential to include feedback. The “Great White Sharks” video was eliminated due to the fact that without water surrounding the user, creating an immersive and realistic underwater scene is less plausible. Roller coaster and Skiing videos had vertical movements which are said to cause nausea. The 1941 Battle video had explosions, debris flying around with a windy atmosphere which would meet our requirements for wearable and non-wearable feedback. Hence it was chosen to be played in the prototype.

¹¹https://www.youtube.com/watch?v=0wC3x_bnnps&t=161s

¹²https://www.youtube.com/watch?v=HNOT_feL27Y

¹³<https://www.youtube.com/watch?v=VdVpQt71cG8>

¹⁴<https://www.youtube.com/watch?v=BUkgWJjbrlk>

¹⁵<https://www.youtube.com/watch?v=SZ0fKW5PttM>

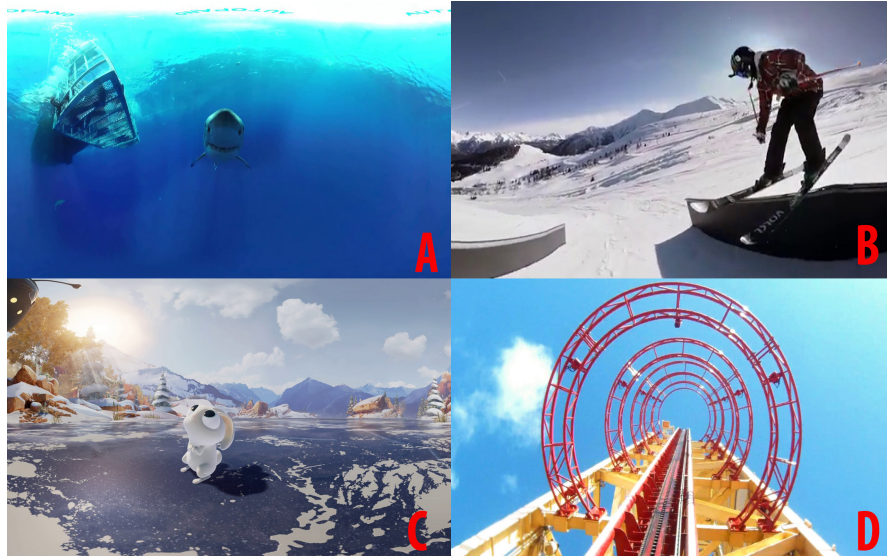


FIGURE 4.8: Other 360° movies that were considered. a) Great White Sharks, b) Skiing - GoPro VR: Omni Trailer, c) Invasion 360° VR, d) Roller Coaster 360°

4.3.4 Implementation of Control Driver

The purpose of the control driver is to simplify and facilitate the communication between the Game Engine and the connected haptic interface. Control Driver communicates to the game engine via a socket connection and the communication to the feedback interfaces is facilitated through the serial port. As can be seen from the figure 4.9, the control driver provides a graphical user interface to test the haptic interfaces. In the figure, the application can control each of the fans where the sliders represent the intensity. The application was written using JavaScript(“Node JS”, ¹⁶).

Control Driver communicates with the peripheral interfaces through serial port connection. Wind module was connected to the PC using USB connection and the vest was connected via Bluetooth connection. The Bluetooth connection was established by creating a virtual port in the windows system to which the CD communicates. As can be seen from figure 4.9, CD also provides a GUI to test and debug each of the individual components in the interface.

¹⁶<https://nodejs.org/en/>

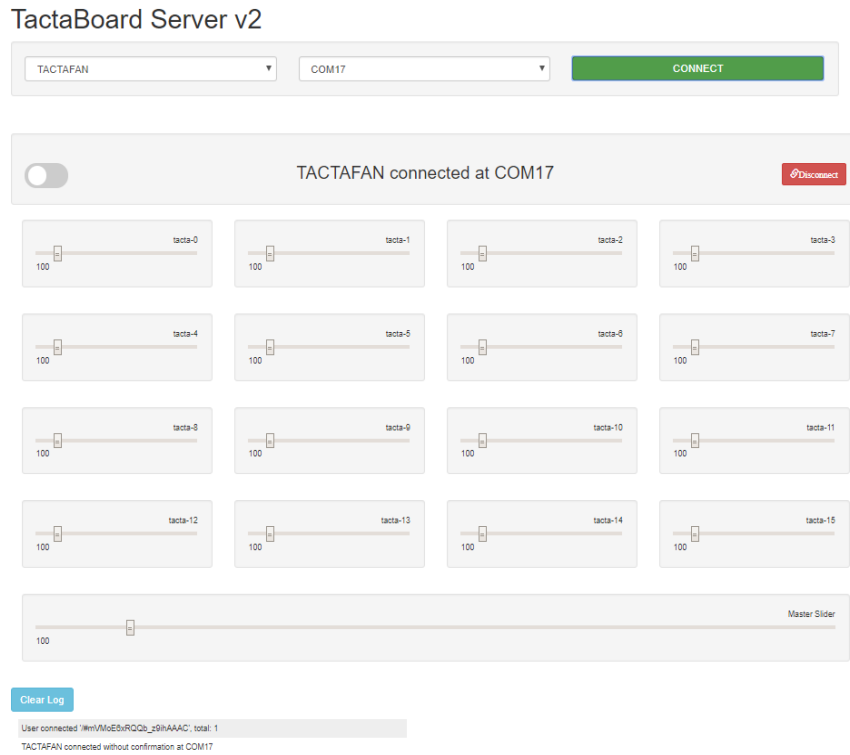


FIGURE 4.9: TactaServer GUI

4.4 Working prototype

The working prototype was designed based on the system architecture. The interfaces were triggered according to the actions in the digital content being played. Figure 4.10 shows some of the scenes that provide feedback. The feedback signals were timed precisely to ensure plausible feedback.



(a) Floor vibrations simulate the feedback of tanks passing by. (b) Wind and flying debris represented using wind and vest modules.

FIGURE 4.10: Prototype feedback scenes

Chapter 5

User Evaluation

We conducted a user study to understand how haptic feedback influences the user's presence in a 360° cinematic environment. This chapter describes the experiment that was carried out in detail.

5.1 Evaluation Purpose

The purpose of the evaluation is to investigate the influence of haptic feedback in a 360° cinematic environment in terms of sense of presence. We also looked into comparing wearable haptics with non-wearable haptics in terms of sense of presence. For the experiment, we have four hypotheses. They are as follows:

- Hypothesis 1 (H1): The inclusion of haptic feedback in a 360° cinematic environment increases the sense of presence significantly.
- Hypothesis 2 (H2): The inclusion of wearable haptic feedback in a 360° cinematic environment increases the sense of presence significantly.
- Hypothesis 3 (H3): The inclusion of non-wearable haptic feedback in a 360° cinematic environment increases the sense of presence significantly.
- Hypothesis 4 (H4): There is a significant difference in the sense of presence between wearable and non-wearable wearable feedback when experiencing a 360° movie.

5.2 User Experiment Design

For the purpose of our study, we referred to previous studies that were conducted in the domain of wearable and non-wearable feedback. We also explored the prospects of introducing spatial orientation to the system, but later opted against it due to the tracking limitations of Oculus Rift. More about this is discussed in the future section.

We had two independent variables for the experiment - wearable feedback and non-wearable feedback. Both had two levels: present or not. Hence we had a factorial design of 2 by 2 with four conditions in total as shown in Table 5.1.

	no wearable feedback	wearable feedback
no non-wearable feedback	HMD	HMD+W
non-wearable feedback	HMD+NW	ALL

TABLE 5.1: Factorial design

5.2.1 Balanced Latin Square

The experiment consisted of a within-subject design. Hence each participant tried all four conditions. As the experiment features within-subject design, we used balanced Latin square design to counter-balance the order effect. There were four conditions for the experiment; therefore, 4 by 4 balanced Latin square design was used, which can be seen in Table 5.2.

A	B	C	D
B	D	A	C
D	C	B	A
C	A	D	B

TABLE 5.2: 4 by 4 Balanced Latin Square Design

where

A	=	HMD	
B	=	HMD	+ Wearable Feedback (W)
C	=	HMD	+ Non-Wearable Feedback (NW)
D	=	HMD	+ Wearable and Non-wearable Feedback (ALL)

5.2.2 Experimental Setup

The study was carried out at the Student Lab in HIT Lab NZ and setup can be seen in Fig. 5.1.



FIGURE 5.1: Experimental setup

As per the prototype described in chapter 4, the key components were - Oculus Rift, vest, floor module, wind Module and a desktop PC. Since we were following a within-subject study, we wouldn't want to exhaust our users. Hence the 360° video in Chapter 4.4 "1941 Battle Reincarnation" was trimmed down to 2.5 minutes which would give sufficient time for the user to observe the surroundings. The feedback was timed to precision so as to sense. The video had debris flying around from shootings along with smoke and wind. Ground vibrations were timed to mimic the effects of tanks passing by or firing.

5.2.3 Procedure

The procedure that was followed for each participant according to the time line of events is given below.

1. At the beginning of the experiment, participants were given a general overview and explanation of the project. This was followed by handing out the information sheet and the consent form for the participant to read and sign. The information sheet and the

consent form are provided in Appendix A.

2. Participants answered a pre-experiment questionnaire. The pre-experiment questionnaire collected demographic information and can be found in Appendix B.
3. The pre-experiment questionnaire was followed by a detailed briefing on the experiment which includes the description of the process.
4. Participants were then instructed to wear the vest and the HMD. Later, they were instructed to stand inside the cage structure
5. At this point, participants were ready to begin the experiment. They undergo the experiment's four conditions in a sequence defined by the balance latin square chart. At the end of each condition, the participants answered a per-condition questionnaire to rate their experience.
6. After completing the four conditions, they answered a post-experiment questionnaire to give feedback on their overall experience.
7. Finally, the study concluded with a debriefing session to clarify any issues in the questionnaire responses and a short interview to discuss their experience with each haptic interface.

5.2.4 Experimental Task

The experiment began with briefing followed by the pre-experiment questionnaire. Since experiment is a within-subject design as explained above, each participant went through all four conditions, A, B, C, and D, as described in Table 5.2. The tasks for each of these conditions were as follows.

Condition A: The participant watches the “1941 battle 360° reenactment” video through HMD. No feedback will be given in this case. After two and half minutes of video, they proceed to answer the per-condition questionnaire.

Condition B: The participant watches the same 360° video through the HMD. However, for condition B, there will be vibration feedback from the vest. After the video, they answer the per-condition questionnaire.

Condition C: In condition C, the participant watches the 360° video along with non-wearable feedback given by the wind and the floor module. The video is followed by a questionnaire.

Condition D: For condition D, the participant watches the 360° video along with

wearable and non-wearable feedback. In this case, the vest, floor and wind modules are activated. The participant answers the questionnaire after the video.

After the last condition, the participant filled out the post-experiment questionnaire.

5.2.5 Measure - Sense of Presence

The primary objective of the experiment was to measure the sense of presence. In our study, we were interested in measuring the sense of presence which is a psychological state where a person experiencing a virtual environment has a feeling of being there in a virtual environment. The sense of presence can be measured in different ways, for example, measuring brain activity, physiological measures or conventional questionnaire [33]. Most of these measures are specific to a certain application. We choose the igroup presence questionnaire (IPQ) ¹ as it measures the presence components (general presence, spatial presence, realism, and involvement) we are interested in and has been widely used in previous research. IPQ is composed of 14 items, which are rated on the seven-point Likert scale [34]. These 14 items are further divided into three sub-scales and one general item. The three sub-scales are highlighted below.

- Spatial Presence: the sense of being physically present in the virtual environment
- Involvement: measuring the attention devoted to the virtual environment and the involvement experienced
- Experienced Realism: measuring the subjective experience of realism in the virtual environment

These three scales are independent of each other. The fourth item of the IPQ is the general presence. It is a general sense of being in the virtual environment and has an effect on all three sub-scales especially the spatial presence [35]. For our experiment, we used IPQ to measure presence for each experimental condition. The per-condition questionnaire is provided in Appendix B.

¹IPQ <http://www.igroup.org/pq/ipq/items.php>

5.2.6 Questionnaire

The questionnaire was set up using “Qualtrics”². The infrastructure for this was provided by the University of Canterbury. Using this platform simplified the analysis process for us and increased the convenience of answering for the participants. Figure 5.2 shows the screenshot of the questionnaire.

The screenshot shows a questionnaire interface with the University of Canterbury logo at the top. Below the logo is a red horizontal bar. The questionnaire consists of several questions with Likert-scale response options:

- Question 1:** "In the computer-generated world i had a sense of 'being there'"
 - Not at all (left)
 - Very Much (right)
- Question 2:** "Somehow I felt that the virtual world surrounded me"
 - Fully disagree (left)
 - Fully agree (right)
- Question 3:** "I felt like I was just perceiving pictures"
 - Fully disagree (left)
 - Fully agree (right)
- Question 4:** "I did not feel present in the virtual space."
 - Did not feel (left)
 - felt present (right)
- Question 5:** "I had a sense of acting in the virtual space, rather than operating something form outside"
 - fully disagree (left)
 - fully agree (right)
- Question 6:** "I felt present in virtual space"
 - fully disagree (left)
 - fully agree (right)
- Question 7:** "How aware were you of the real world surrounding while navigating in the virtual world? (i.e. sounds, room temperature, other people, etc.)?"
 - Extremely Aware (left)
 - Moderately aware (right)
 - Not Aware at all (right)

FIGURE 5.2: Screenshot of the questionnaire in Qualtrics

5.2.7 Pilot study

An initial pilot study was carried out on three participants, two males and one female. With the study, we were able to test all four conditions with the questionnaire. It was a full-on study in which participants went through the same experience as the actual user experiment. The pilot study was carried out to detect any issue with the system or procedure for the experiment. The data collected from the pilot study was not included in the final data. As a result of the pilot study, we were able to eliminate few issues

²<https://www.qualtrics.com/>

like the amplifier shutting down due to prolonged usage, rectify bugs in the Qualtrics questionnaire interface and fine tune the experimental setup.

Chapter 6

Results

This chapter presents the results and analysis of the user study. In the user study, participants were asked to complete pre-experiment questionnaire, four per-condition questionnaires, and a post-experiment questionnaire. The pre-experiment questionnaire aimed to collect demographic information of the participants. The per-condition experiment questionnaire consisted of the standard IPQ presence questionnaire. The post-experiment questionnaire was designed to gather the preferences of the participants and qualitative feedback.

The IPQ is a standard scale for measuring sense of presence in a virtual reality experience. The questionnaire can be divided into subgroups that measure General Presence (GP), Spatial Presence (SP), Involvement (INV) and Realism (REAL) as shown in Table 6.1. After inverting the negative questions in IPQ, The sum of all the scores can be used to analyze the overall experience in the virtual environment.

From the analysis of the IPQ questionnaire, we found that spatial presence, realism, and overall-experience are significantly higher when wearable feedback is included in a 360° cinematic experience. There was also a significant increase in spatial presence, involvement, realism, and overall-experience when wearable feedback was included in the 360° cinematic experience. We also found that spatial presence of non-wearable haptic feedback was significantly higher than wearable haptic feedback.

TABLE 6.1: Igroup Presence Questionnaire

English IPQ Items					
Number	PQ/II Nr. (internal)	IPQ item name	shortcut	loading on ...	English question
1	s62	G1	sense of being there	PRES	In the computer generated world I had a sense of "being there"
2	s44	SP1	sense of VE behind	SP	Somehow I felt that the virtual world surrounded me.
3	s30	SP2	only pictures	SP	I felt like I was just perceiving pictures.
4	s28	SP3	not sense of being in v. space	SP	I did not feel present in the virtual space.
5	s31	SP4	sense of acting in VE	SP	I had a sense of acting in the virtual space, rather than operating something from outside.
6	s33	SP5	sense of being present in VE	SP	I felt present in the virtual space.
7	s64	INV1	awareness of real env.	INV	How aware were you of the real world surrounding while navigating in the virtual world? (i.e. sounds, room temperature, other people, etc.)?
8	s37	INV2	not aware of real env.	INV	I was not aware of my real environment.
9	s40	INV3	no attention to real env.	INV	I still paid attention to the real environment.
10	s38	INV4	attention captivated by VE	INV	I was completely captivated by the virtual world.
11	s48	REAL1	VE real (real/not real)	REAL	How real did the virtual world seem to you?
12	s7	REAL2	experience similar to real env.	REAL	How much did your experience in the virtual environment seem consistent with your real world experience ?
13	s59	REAL3	VE real (imagined/real)	REAL	How real did the virtual world seem to you?
14	s47	REAL4	VE wirklich	REAL	The virtual world seemed more realistic than the real world.

6.1 Demographics

After receiving approval from the University's Human Ethics committee, 32 participants were recruited. Out of the 32 participants, 21 (65.625 %) were male and 11 (34.37 %) were female. The age of participants varied between 18 to 36 years with a mean of 26.25 years. Eleven out of 32 participants had never used HMD before and 14 participants used only a few times per year. Eleven participants had never watched 4D movies (movies with sensor-equipped movie seats, wind, strobe, fog, rain, and scents) and the rest of the participants (21) had watched 4D movies a few times per year. Out of the 32 participants, 15 strongly agreed, 11 agreed and 6 had a neutral opinion on the statement that they would like to be present in the movie rather than viewing a conventional movie with visuals and audio.

6.2 Quantitative Measures

In the user study, there were two independent variables (IVs): wearable and non-wearable feedback. As shown in the table 5.1 we had a factorial design of 2 by 2 with four conditions in total. The dependant variable was the participant's response to the questionnaire for presence. IPQ presence questionnaire was used as a per-condition questionnaire and for each question, participants had to rate between 0 - 6. We computed the scores for spatial presence, involvement, realism and overall experience by adding the ratings for the corresponding questions and further analyzed them to see if there were any statistically significant differences between independent variables.

6.2.1 Spatial Presence

The descriptive statistics for spatial presence for the four conditions are presented in Table 6.2. The mean of scores of conditions HMD+W (mean = 19.47, SD = 5.38), HMD+NW (mean = 20.69, SD = 4.91) and ALL (mean = 22.03, SD=5.84) are greater than the mean score of condition HMD (mean = 14.68, SD = 6.98). From these statistics, we can infer that the spatial presence experienced by participants is greater in conditions with haptic feedback compared to the condition with no feedback. The box plots in

TABLE 6.2: Mean and standard deviation scores of Spatial Presence

Measure	HMD	HMD+W	HMD+NW	ALL
Mean	14.87	19.47	20.69	22.03
Std. Deviation	6.98	5.38	4.91	5.84

Figure 6.1 shows the distribution of the spatial presence scores and they indicate that the median of HMD+W, HMD+NW and ALL was more than HMD condition. A Shapiro-Wilks test was used as a test of normality and it indicated that the data were statistically normal. A two-way repeated measures ANOVA analysis on the data showed that there was statistically significant difference in the spatial presence ($F(1,31)=13.945$, $p=0.001$) when wearable haptic feedback was included in a 360° cinematic experience. There was also a statistically significant difference in the spatial presence ($F(1,31)=32.22$, $p<0.001$) when non-wearable haptic feedback was included in a 360° cinematic experience. There was a significant interaction effect between the two IVs ($F(1,31)=6.99$, $p=0.013$).

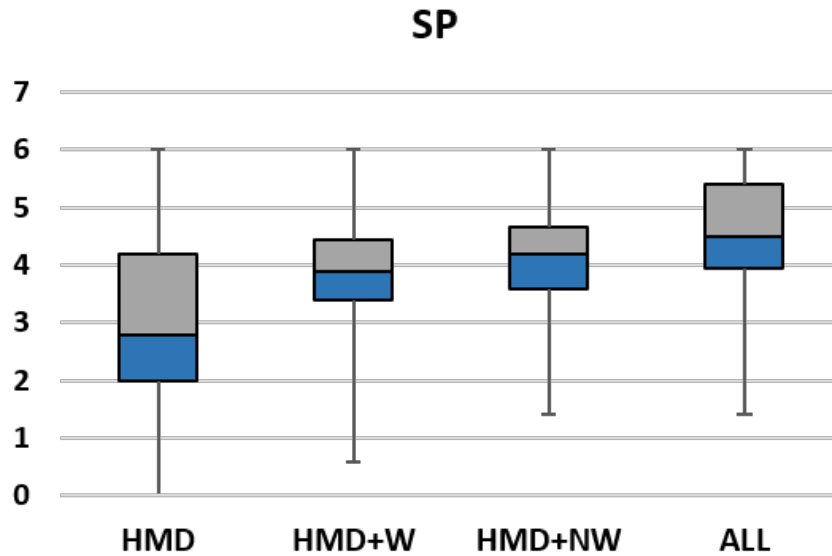


FIGURE 6.1: Box-plot for Spatial presence

6.2.2 Involvement

The descriptive statistics for Involvement for the four conditions are presented in Table 6.3. The mean of Involvement scores of conditions HMD+W (mean = 14.4, SD = 3.99), HMD+NW (mean = 15.06, SD = 3.88) and ALL (mean = 15.84, SD=5.88) are more than the mean score of condition HMD (mean = 12.97, SD = 5.43). From these statistics, we can infer that the involvement of the participants was greater in conditions with haptic feedback compared to condition with no haptic feedback.

TABLE 6.3: Mean and standard deviation scores of Involvement

Measure	HMD	HMD+W	HMD+NW	ALL
Mean	12.97	14.4	15.06	15.84
Std. Deviation	5.43	3.99	3.88	5.88

The box plots in Figure 6.2 show the distribution of the Involvement scores and they indicate that the median of HMD+W, HMD+NW, and ALL conditions were greater than the HMD condition. The Shapiro-Wilks test was used as a test of normality and it indicated that the data were statistically normal. A two way repeated measures ANOVA analysis on the data showed that there was a statistically significant difference in Involvement ($F(1,31)=13.945$, $p=0.001$) when non-wearable haptic feedback was included in the 360° cinematic experience. There was no significant difference in Involvement ($F(1,31)=2.612$, $p=0.116$) when wearable haptic feedback was included in the 360° cinematic experience.

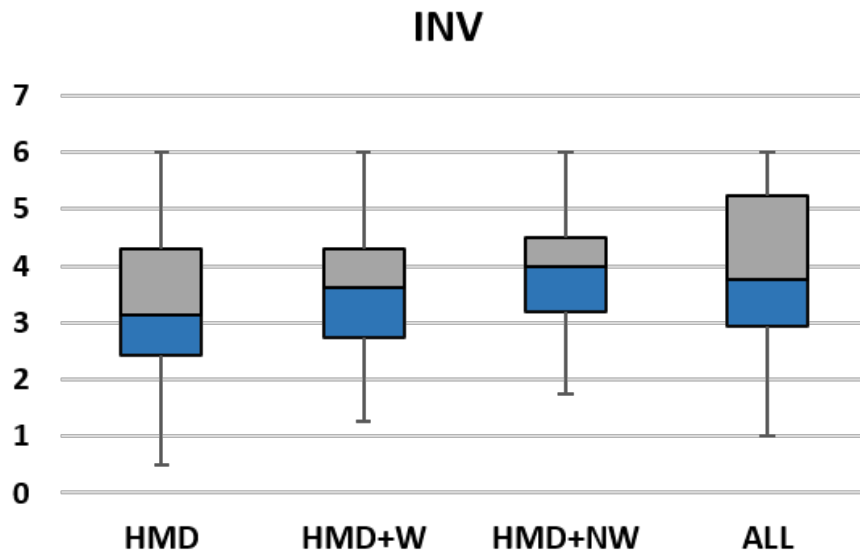


FIGURE 6.2: Box-plot for Involvement

There was no significant interaction effect between the two IVs ($F(1,31)=0.404$, $p=0.53$) between wearable and non-wearable haptic feedback.

6.2.3 Realism

The descriptive statistics for Realism scores for the four conditions are presented in Table 6.4. The mean of Realism scores of conditions HMD+W (mean = 11.53, SD = 4.73), HMD+NW (mean = 11.68, SD = 3.51) and ALL (mean = 12.75, SD=4.51) were greater than the mean score of condition HMD (mean = 9.84, SD = 5.11). From these statistics, we can infer that the Realism scores of the participants were greater in conditions with haptic feedback compared to the condition with no haptic feedback.

TABLE 6.4: Mean and standard deviation scores for REALISM

Measure	HMD	HMD+W	HMD+NW	ALL
Mean	9.84	11.53	11.68	12.75
Std. Deviation	5.11	4.73	3.51	4.51

The box plots in Figure 6.3 show the distribution of the Realism scores and they indicate that the median of HMD+W, HMD+NW, and ALL conditions were greater than HMD condition.

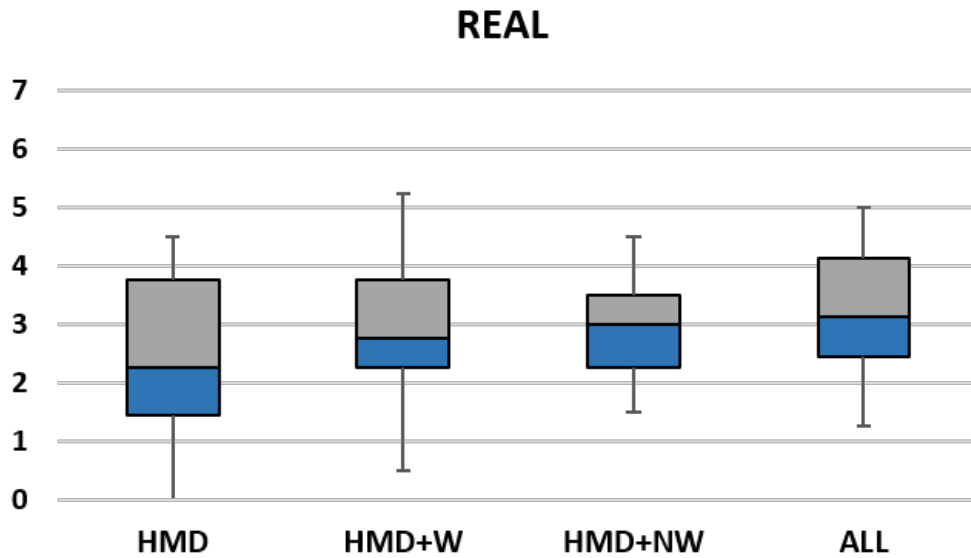


FIGURE 6.3: Box-plot for Realism

A Shapiro-Wilks test was used as a test of normality and indicated that the data were statistically normal. A two-way repeated measures ANOVA analysis on the data showed that there was a statistically significant difference in Realism ($F(1,31)=7.118$, $p=0.012$) when wearable haptic feedback was included in the 360° cinematic experience. There was a statistically significant difference in Realism ($F(1,31)=6.3$, $p=0.017$) when non-wearable haptic feedback was included in the 360° cinematic experience. There were no significant interaction effects in Realism Scores ($F(1,31)=0.37$, $p=0.55$) between wearable and non-wearable haptic feedback.

6.2.4 Overall Experience

The descriptive statistics for Overall Experience scores for the four conditions are presented in Table 6.5. The mean of Overall Experience scores of conditions HMD+W (mean = 49.28, SD = 12.34), HMD+NW (mean = 51.63, SD = 10.29) and ALL (mean = 55.25, SD=14.43) were greater than the mean score of condition HMD (mean = 40.84, SD = 16.05). From these statistics, we can infer that the Overall Experience scores of the participants were greater in conditions with haptic feedback compared to the condition with no haptic feedback.

A Shapiro-Wilks test was used as a test of normality and it indicated that the data were statistically normal. A two-way repeated measures ANOVA analysis on the data showed

TABLE 6.5: Mean and standard deviation scores for Overall Experience

Measure	HMD	HMD+W	HMD+NW	ALL
Mean	40.84	49.28	51.63	55.25
Std. Deviation	16.05	12.34	10.29	14.43

that there was a statistically significant difference in Overall Experience ($F(1,31)=11.06$, $p=0.002$) when wearable haptic feedback was included in the 360° cinematic experience. There was a statistically significant difference in overall experience ($F(1,31)=29.74$, $p<0.01$) when non-wearable haptic feedback was included in the 360° cinematic experience. There were no significant interaction effect in overall experience ($F(1,31)=3.62$, $p=0.06$) between wearable and non-wearable haptic feedback.

6.3 Post-experiment Questionnaire

To further understand the reasons behind choices the participants made, their comments on the system and opinions were recorded. Twenty-seven out of 32 reported that there were no issues with the experience and that they enjoyed it very much. Here are the comments from five participants who had some problems during the experiment.

- “I wore heeled boots so balancing was a bit hard”.
- “I didn’t feel the wind much, the video slowed down suddenly for a few seconds, targeted sound effects and vibrations may enhance the experience”.
- “I think the wire of headphone make you little bit aware that you are not in the virtual world, as it is the only thing touches your body”.
- “Bit cyber dizziness, but not significant. The haptic vest was very cumbersome to wear and felt more like a baggage than convenience”.

6.3.1 Qualitative measures

Participants were asked to complete post-experiment questionnaire after completing the four conditions. For the question about preferred condition, 1 participant chose HMD, 3 participants chose HMD+W, 7 participants chose HMD+NW and 21 participants chose ALL condition as shown in Figure 6.4. A chi-square goodness of fit test was calcu-

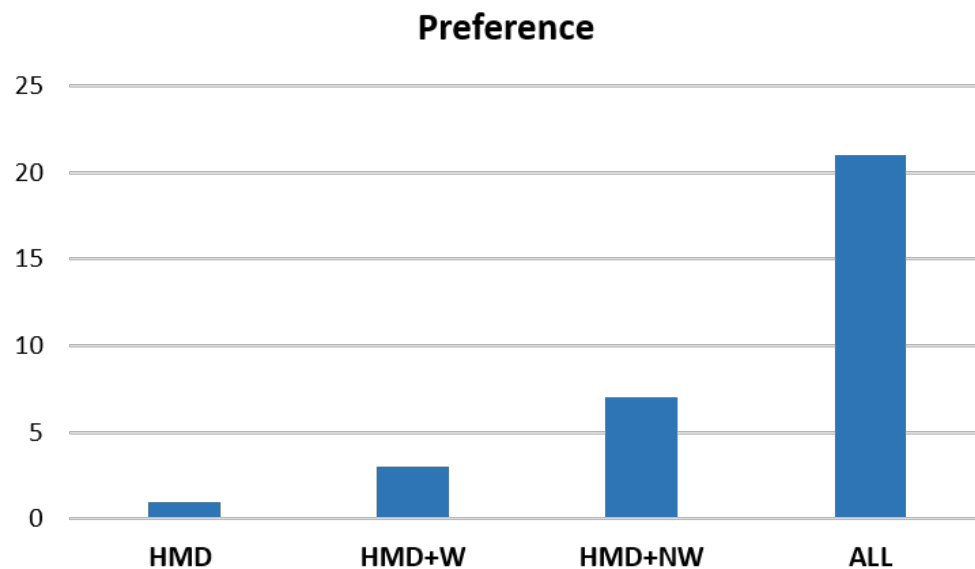


FIGURE 6.4: Preference

lated comparing the participant preferences with the expected frequency of even distributed preference (8,8,8,8). Significant deviation from hypothesized values was found ($X^2(3)=30.5$, $p<0.001$).

As shown in Figure 6.5, 20 participants chose the ALL condition as the one inducing the greatest sense of presence, eight participants chose HMD+NW, two participants chose HMD+W and the other two participants chose HMD as the conditions inducing the most sense of presence.

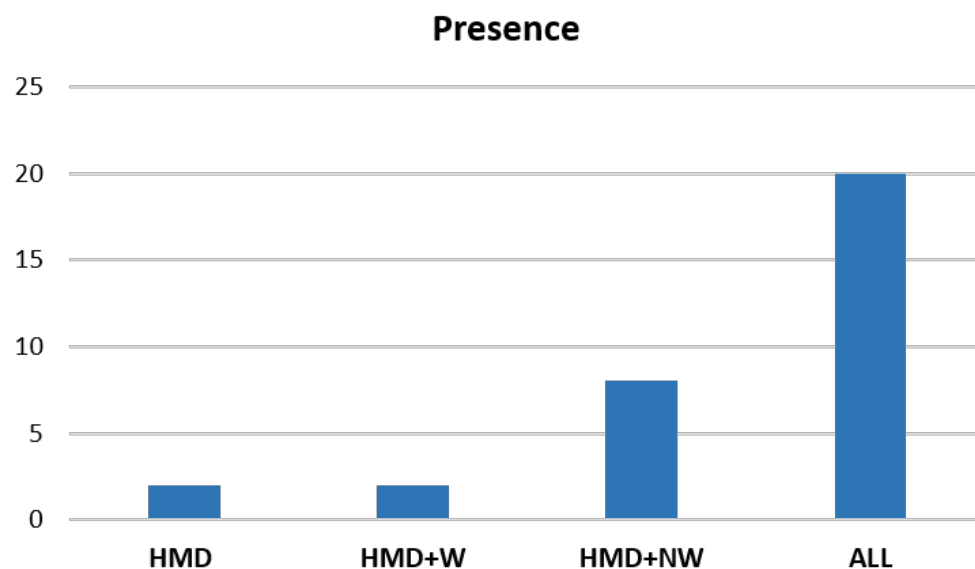


FIGURE 6.5: Presence

A chi-square goodness of fit test was calculated comparing the participant choice of highest presence condition with the expected frequency of even distributed choice (8,8,8,8). Significant deviation from hypothesized values was found ($\chi^2(3)=27, p<0.001$).

Other comments by the participants are included below.

- The way the video was shot (the distance from where the viewer feels they're viewing it) made it feel a little larger than it's supposed to be. Had it been shot from a little farther away, the people and objects in the video would seem more proportionate to the real environment. This would make the participant feel more 'present' in the environment.
- Better picture and audio clarity could have enhanced the experience.
- Positioning myself in VR and jumping from scene to another felt disconnected to the story line. I personally felt incomplete in story line with VR visual.
- Vibrations were of right duration but different intensities to real-world effects of Tanks and Arty.
- I felt as the videos progressed I learned what was happening in them and felt less present in the environment
- I liked the floor and the wind but sometimes I was expecting wind when there wasn't any or expecting it to come from a different direction based on the video.
- If I were to watch a movie I would prefer watching it with the audio + video + floor + west. I felt the wind didn't have much impact. Maybe a more rigorous "wind system" might change this.
- The A+V+F+W+V works best in the settings similar to that envisioned in the experiment.
- I love the simulations
- Felt like spending more time enjoying it.

- it was a great first glance in the virtual world for me

Chapter 7

Discussion

This chapter further analyzes and discusses the results of the user study. It also explores the possible explanations that support our findings.

7.1 Study Results

Hypothesis H1 states that the users would perceive a higher level of presence when haptic feedback is given. The results and analysis show that the sense of presence scores of conditions HMD+W, HMD+NW and HMD+W+NW is significantly higher than the scores of condition HMD confirming **H1**. There is a statistically significant difference in spatial presence scores after adding wearable haptic feedback confirming **H2**. There is a statistically significant difference in spatial presence scores after adding non-wearable haptic feedback confirming **H3**. On further analyzing the IPQ three sub-scales (realism, spatial presence, involvement) and the general item (general presence), we found wearable haptic feedback has a significant difference for realism and overall experience. There is also a significant difference between involvement, realism and overall experience scores for non-wearable haptic feedback. There is a statistically significant difference in spatial presence between wearable and non-wearable feedback and hence, we confirm **H4**.

7.2 Limitations

- The wind system has 16 static individual fans distributed around. The wind module had a slight latency. We tried to compensate this by triggering the signals a slightly ahead of time. A more responsive wind system might produce a better result.
- Spatial Orientation - we decided against the implementation due to the limitations of Oculus Rift in terms of tracking. We could track the entire body, it could be implemented effectively. In our video, there are visual cues of instances of explosions from multiple directions. Hence if spatial orientation was present, it could have had a positive impact on the sense of presence.
- We limited the number of participants to 32. We might be able to get more accurate results if we had a bigger user group.
- The video had a few jump scenes which might have had an impact on the sense of presence. One participant commented on the same during the interview after the experiment.
- The physical feeling of the HMD cable dangling around the shoulder could also have an impact on the sense of presence. In our study, we didn't implement the top mounted cable management which might have been better.
- Almost 3/4th of our participants never experienced VR environments. The novelty factor might have been influential in our study.
- The vest was made keeping in mind the range of movements and snug fit. The participants were asked to remove their jacket if they had one on but the kind of dress material they wore could have an impact on how effective the feedback sensation is.
- In our study, the participants were standing while watching the video(duration of 2.5 minutes), it would be interesting to see whether the results change if they are made to watch the video while sitting.

7.3 Further Discussion

After analyzing the questionnaire and qualitative feedback, we were able to respond to our research questions. Does haptic feedback improve the sense of presence in a 360° cinematic environment? The results show that there is a significant increase in sense of presence by providing either wearable or non-wearable haptic feedback. We also found significant improvement involvement and realism with the inclusion of feedback. From these results, we can conclude that the overall experience of watching 360° movie increases with haptic feedback.

Does wearable haptic feedback improve the sense of presence more compared to the non-wearable haptic feedback? From the descriptive statistics of the previous chapter, it is evident that the sense of presence, involvement and realism scores of non-wearable haptic feedback is more than the wearable haptic feedback. Even though the spatial presence of non-wearable feedback was significantly higher than wearable feedback there was no statistically significant increase in realism, involvement and overall experience.

In the post-experiment questionnaire, participants were asked their preferred feedback and 21 out of 32 preferred having both wearable and non-wearable feedback in the system. When asked about the choice of maximum presence in the system, 20 participants chose the system with both wearable and non-wearable feedback.

Chapter 8

Conclusion and Future Work

This chapter briefly summarizes the thesis and the conclusions drawn from the results. It also identifies possible future areas of research.

8.1 Conclusion

In this thesis, we studied the influence of haptic feedback on the sense of presence in a 360° cinematic environment. For the study, we created a simulation system using Unreal Engine, wind and floor modules (non-wearable components) and vest module (wearable component) to provide an immersive environment. Floor module provided ground vibrations using actuators, wind module provided wind feedback using fans and vest modules provided vibrotactile feedback using offset DC motors. The Unreal Game engine was used to integrate all the modules and displaying 360° cinematic environment.

A user experiment was carried out using the prototype to study the influence of haptic feedback in a 360° Cinematic environment. We investigated the effect of feedback on the sense of presence between wearable and non-wearable feedback. There were 32 participants in the user study. The sense of presence was measured using the IPQ questionnaire. The study results showed that the users had a significantly higher sense of presence in the conditions where there was haptic feedback. The results also indicated that there was no significant difference in sense of presence between wearable and non-wearable haptic feedback in a 360° VR environment. There were limitations to the study which are mentioned in the previous chapter.

8.2 Future Work

There are several possibilities for future work. Some of them are identified in the limitation section of Chapter 7. Other possibilities are as follows.

- **Spatial orientation** In the case of vest and fan, at any point in time, the intensity of vibration given is the same for all the units though they can be individually controlled. The tracking limitation of the HMD was the primary reason for not implementing spatial orientation.

Oculus rift tracks only the spatial orientation of the head and not of the whole body. Since the vest is in the torso, the user could be looking to his/her left /right but there is no way to obtain the orientation of the torso other than putting a tracker. The same could be said for the wind module. The effect of spatial orientation in the sense of presence could be a potential future expansion.
- **Inclusion of different haptic feedback interfaces** During the design phase of our prototype, we came across “teslasuit”, ¹. Since it is not commercially available during the time of our study, we couldn’t use/test it. The concept of this vest includes haptic feedback(higher resolution as it is a full body suit), motion capture and positioning and climate control(temperature range). Though this vest would be much restrictive than our design, it would be interesting to study the sense of presence outside the scope of cutaneous senses.
- **Feedback as an information display** In our study, we used the feedback interfaces as a means for feedback. There have been previous studies in terms of using haptic interfaces as a means of information display. For example, using feedback to navigate the user through the virtual environment. Incorporating these two could have a system that provides feedback and at the same time acts as an information display.
- **Adding interaction** Previous studies [4, 6] have shown that interaction and self-inclusion in VR improves the sense of presence. It would be interesting to study the immersiveness of a system that integrates interaction, self-inclusion, and haptic feedback.

¹<https://teslasuit.io/>

- **Multi-sensory immersion** Previous studies have shown that Olfactory Stimuli Increase Presence in Virtual Environment [36]. the inclusion of other sensory cues and investigating its effects on the sense of presence is another step forward in the direction of multi-sensory immersion.

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Appendix A

Appendix A: Information Sheet and Consent Form



HUMAN ETHICS COMMITTEE

Secretary, Rebecca Robinson
Telephone: +64 03 369 4588, Extn 94588
Email: human-ethics@canterbury.ac.nz

Ref: HEC 2018/01/LR

19 January 2018

Prasanth Sasikumar
HIT Lab NZ
UNIVERSITY OF CANTERBURY

Dear Prasanth

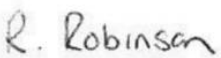
Thank you for submitting your low risk application to the Human Ethics Committee for the research proposal titled "Haptic Contact in Immersive Virtual Environments".

I am pleased to advise that this application has been reviewed and approved.

Please note that this approval is subject to the incorporation of the amendments you have provided in your emails of 8th and 12th January 2018.

With best wishes for your project.

Yours sincerely

pp. 

Professor Jane Maidment
Chair, Human Ethics Committee



Human Interface Technology Lab
Telephone: +64 3 364 2403
Email: prasanth.sasikumar@pg.canterbury.ac.nz
07/01/2018

Introduction of sense of touch in realistic virtual environment Information Sheet for participant

I am Prasanth Sasikumar, a master's student at the HIT Lab NZ and I am conducting this research as part of my postgraduate studies. I am interested in the role of haptic vest in improvising presence of users in cinematic environments.

The following researchers will help me with this study: Professor Rob Lindeman (my supervisor), Gun Lee (Senior Research Fellow, UniSA), and Simon Hoermann (a researcher at the HIT Lab)

If you choose to take part in this study, your involvement in this project require you to wear a head mounted display (Oculus Rift), a vest (which provides a vibrational feedback similar to mobile phones).

As a follow-up to this investigation, you will be asked to

- a) Have to stand in a cage enabled with ground vibration and wind feedback and watch a 5 minute 360 degree video.
- b) Have to watch the same video in Oculus Rift and cage with the vest turned on.
- c) You will be asked to complete several questionnaires, before, during, and after the experiment. The estimated total time is 30-40 minutes. You will be compensated for your time with a 10\$ gift voucher.

During your time in the virtual environment, your reactions will be recorded. However, no identifiable information will be collected at any point in this study (e.g. name, address).

Using Oculus Rift bear a risk of dizziness (also known as cyber-sickness) due to the use of the head mounted display. Many factors that can cause cyber-sickness have been mitigated through our current hardware system, however, there is still a chance that you might experience some of the symptoms. You are allowed to stop the experiment at any time or extend the period between sessions to as long as you need. We will also offer a couch where you can relax until the symptoms have faded.

Participation is voluntary and you have the right to withdraw at any stage without penalty. You may ask for your raw data to be returned to you or destroyed at any point. If you withdraw, I will remove information relating to you. However, once analysis of raw data starts after the completion of the user study, it will become increasingly difficult to remove the influence of your data on the results.

The results of the project may be published, but you may be assured of the complete confidentiality of data gathered in this investigation: your identity will not be made public without your prior consent. To ensure anonymity and confidentiality, the recordings will only be accessible by my supervisors and me. The data will be kept securely stored for a minimum period of 5 years on storage systems within the University of Canterbury, and securely destroyed after that.

Prasanth Sasikumar

A thesis is a public document and will be available through the UCLibrary. The outcomes of this research may be published in scientific outlets such as conferences and journals as well as part of my Master's thesis. Major dissemination of this research will be announced on the Facebook page of the HIT Lab NZ (www.facebook.com/HITLabNZ) where a link to the published documents will be provided.

Please indicate to the researcher on the consent form if you would like to receive a copy of the summary of results of the project.

The project is being carried out under the supervision of Professor Rob Lindeman, who can be contacted at gogo@hitlabnz.org and +64 3 364 2403. He will be pleased to discuss any concerns you may have about participation in the project.

This project has been reviewed and approved by the University of Canterbury Human Ethics Committee, and participants should address any complaints to The Chair, Human Ethics Committee, University of Canterbury, Private Bag 4800, Christchurch (human-ethics@canterbury.ac.nz).

If you agree to participate in the study, you are asked to complete the consent form and return it before commencing the experiment.



Human Interface Technology Lab
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Email: prasanth.sasikumar@pg.canterbury.ac.nz

Introduction of sense of touch in realistic virtual environment

Consent Form for participant

- ☐ I have been given a full explanation of this project and have had the opportunity to ask questions.
- ☐ I understand what is required of me if I agree to take part in the research.
- ☐ I understand that participation is voluntary and I may withdraw at any time without penalty. Withdrawal of participation will also include the withdrawal of any information I have provided should this remain practically achievable.
- ☐ I understand that any information or opinions I provide will be kept confidential to the researchers Prasanth Sasikumar, Rob Lindeman, Gun Lee and Simon Hoermann and that any published or reported results will not identify the participants. I understand that a thesis is a public document and will be available through the UC Library.
- ☐ I understand that all data collected for the study will be kept in locked and secure facilities and/or in password protected electronic form and will be destroyed after five years.
- ☐ I understand the risks associated with taking part and how they will be managed.
- ☐ I understand that I can contact the researcher Prasanth Sasikumar (prasanth.sasikumar@pg.canterbury.ac.nz, +64 3 364 2349) or supervisor Professor Rob Lindeman (gogo@hitlabnz.org, +64 3 364 2403) for further information. If I have any complaints, I can contact the Chair of the University of Canterbury Human Ethics Committee, Private Bag 4800, Christchurch (human-ethics@canterbury.ac.nz)
- ☐ I would like a summary of the results of the project send to the email address stated below.
- ☐ By signing below, I agree to participate in this research project.

Name: _____ Signed: _____ Date: _____

Email address (for report of findings, if applicable): _____

Please complete and return this consent sheet to the researcher conducting the experiment before commencing the study

Prasanth Sasikumar

Appendix B

Appendix B: Questionnaires

Pre Experiment questionnaire

What is your Age?

Gender

- ☐ Male
- ☐ Female
- ☐ Gender Diverse
- ☐ Don't want to specify

Have you used any Head-mounted displays before?

- ☐ Not at all
- ☐ few times a year
- ☐ few times a month
- ☐ few times a week
- ☐ Daily

Have you watched 4D movies before? (Movie equipped with sensor-equipped motion seats, wind, strobe, fog, rain and scents)

- ☐ Not at all
- ☐ Few times a year
- ☐ Few times a month
- ☐ Few times a week
- ☐ Daily

I would like to feel present in the movie rather than just looking at visuals and hearing audio.

- ☐ Strongly agree
- ☐ Agree
- ☐ Neither agree nor disagree
- ☐ Disagree
- ☐ Strongly disagree

Per-Condition Questionnaire

In the computer-generated world i had a sense of "being there"

Not at all



Very Much



Somehow I felt that the virtual world surrounded me

Fully disagree



Fully agree



I felt like I was just perceiving pictures

Fully disagree



Fully agree



I did not feel present in the virtual space.

Did not feel



felt present



I had a sense of acting in the virtual space, rather than operating something form outside

fully disagree



fully agree



I felt present in virtual space

fully disagree



fully agree



How aware were you of the real world surrounding while navigating in the virtual world? (i.e. sounds, room temperature, other people, etc.)?

Extremely Aware



Moderaltely aware



Not Aware at all



I was not aware of my real environment.

Strongly disagree



Strongly agree



I still paid attention to the real environment.

fully disagree



fully agree



I was completely captivated by the virtual world

Strongly disagree



Strongly agree

How real did the virtual world seem to you?

Completely real



Not real at all

How much did your experience in the virtual environment seem consistent with your real-world experience?

Not Consistent



Moderately
Consistent



Very Consistent

How real did the virtual world seem to you?

About as real as an
imagined world



Indistinguishable
from the real world

The virtual world seemed more realistic than the real world

fully disagree



fully agree

Post Experiment Questionnaire

Which cinematic experience did you prefer?

- ☐ Audio + Video
- ☐ Audio + Video + vest
- ☐ Audio + Video + floor + wind
- ☐ Audio + Video + floor + wind +vest

Which condition made you feel present more in the cinematic environment?

- ☐ Audio + Video
- ☐ Audio + Video + vest
- ☐ Audio + Video + floor + wind
- ☐ Audio + Video + floor + wind +vest

Did you have any problem during the experiment?

Any other comments on the experiment?